## Manifold-driven spirals and rings

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Seoul

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Figures here:

- P1: Romero-Gomez, Masdemont, Athanassoula, Garcia-Gomez (2006)
- P2: Romero-Gomez, Athanassoula, Masdemont, Garcia-Gomez (2007)
- P3: Athanassoula, Romero-Gomez, Masdemont (2009)
- P4: Athanassoula, Romero-Gomez, Bosma, Masdemont (2009)
- P5: Athanassoula, Romero-Gomez, Bosma, Masdemont (2010)
- P6: Romero-Gomez, Athanassoula, Figueras, Antoja (2011)
- P7: Athanassoula (2012)
- P8: Athanassoula & Romero-Gomez (in prep.)
- P9: Athanassoula et al (LAMOST Data, in prep.)

See also: Harsoula & Kalapotharakos (2009) Harsoula, Kalapotharakos, Contopoulos (2011) Patsis (2006) Romero-Gomez, Masdemont, Garcia-Gomez, Athanassoula (2008) Tsigaridi & Patsis (2013)



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Homoclinic Heteroclinic

Transfer Escaping

P2, P4

The invariant manifolds extend well beyond the neighbourhood of L1 and L2, so they can be responsible for global structures

They can be thought of as tubes that are filled and surrounded by a bundle of orbits

They play a crucial role in the transport of material between different parts of the configuration space. Loosely, the Lyapunov orbits can be thought of as gates between the regions within and the regions outside corotation.



## Time evolution of the invariant manifolds (P1,P3)





P2, P4

### Are rings and spirals short-lived or long-lived?



#### **Spirals**

Secular evolution : With time bars grow longer and more massive. They also rotate slower, so their Lagrangian points get farther from the centre

If no secular evolution ==>short-lived With secular evolution ==>short-lived long-lived, but evolving (but it will take some fine tuning)

![](_page_8_Figure_5.jpeg)

#### Manifolds (like periodic orbits) are only building blocks So their existence is a necessary, but not sufficient condition

Orbits guided by manifolds and orbits trapped by stable periodic orbits coincide in the same galaxy. All orbits together, those driven by the manifolds and those trapped by the stable periodic orbits, will structure the region beyond corotation. More than one mechanism, even in a single galaxy.

#### What about gas and young stars?

The manifolds will drive the dynamics of the old stars and create the background potential in which the gas will fall, be compressed, form young stars etc.

#### Connecting to observations

Morphology Spirals, inner and outer rings, R1, R2, R1R2 (P3)

Properties of spiral arms Preference of trailing (versus leading) (P4) Number of arms: vast majority m=2, but other m possible (P4) Reproduces well spiral arm shapes (P4) Reproduces observational trends with pitch angle (Seigar et al 2006, Martinez-Garcia 2011, P5)

#### Properties of inner and outer rings

Gives ring sizes, location, orientation and morphology in agreement with observations (P4) Finds observed ratio of ring diameters (P4)

Other properties

Can account for rectangular-like bar shape (P5) Photometry (P1) Kinematics (P5) Abundance gradients (P5) The effect of gas (P5)

# MOVIE: Rotate so that the bar is horizontal ===> Frame co-rotating with the bar

#### Watch the motion of individual simulation particles:

Density wave theory Particles cross the arm staying longer in the arm than in the inter-arm

Manifold theory Mean motion (guiding centre motion) is along the arm

![](_page_11_Picture_4.jpeg)

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In bar+spiral cases the Lagrangian points can not be on the bar major axis

![](_page_12_Figure_1.jpeg)

$$\frac{\partial \Phi_{\text{eff}}}{\partial x} = \frac{\partial \Phi_{\text{eff}}}{\partial y} = 0.$$

![](_page_12_Picture_3.jpeg)

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![](_page_13_Figure_0.jpeg)

![](_page_13_Figure_1.jpeg)

![](_page_14_Figure_0.jpeg)

http://195.221.212.246:4780/dynam/movie/MFolds/sgs058\_noorbits.avi

![](_page_15_Picture_0.jpeg)

http://195.221.212.246:4780/dynam/movie/MFolds/sgs058\\_orbits.avi

We have presented a new theory for spiral structure.

It merits the title 'theory' because it is falsifiable.

It relies on confined chaos

We have done a number of comparisons with observations and hope that more will follow. We have gone further, in this respect, than other proposed theories. Some of our tests could have falsified our theory. They did not.

Orbits guided by manifolds and orbits trapped by stable periodic orbits coincide in the same galaxy. All orbits together, those driven by the manifolds and those trapped by the stable periodic orbits, will contribute to spiral structure.

More than one mechanism. Even in one galaxy, more than one mechanism can be active

### The end